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Experimental investigation for a new solar desalination system

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Abstract

The growing scarcity of fresh water is driving the implementation of desalination on an increasingly large scale. However, the energy required to run desalination plants remains a drawback. The idea of using renewable energy sources is fundamentally attractive and many studies have been conducted in this area.

An experimental rig was especially designed and developed in this work in order to produce fresh water by using a new technology of solar distillation. The test rig was designed to study the effect of using concentrators in desalination field. The unit is used to investigate the influence of using concentrators on water production by distillation instead of using normal stills which use direct sun rays only.

A chain of experimental designations was introduced by the group, Firstly a new Solar Desalination System (SDS) was developed with specific dimensions for the parabolic reflector and the absorber. Three more modifications were conducted to the system. The influence of different environmental, design and operational parameters on the solar distillation unit productivity have been investigated in each case.

The different rig designs have shown a great progress in water productivity especially with the last modification however, improvements were coupled with rising cost.

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1. Introduction

Desalination technologies that are currently practiced have a further constraint; that it is driven almost entirely by the combustion of fuels. These fuels are still of finite supply, pollute the air, and contribute to the risk of global climate change. Because of cost free and clean energy, low operating cost, little maintenance, and no moving parts involved in these systems, solar distillation is preferred to other processes of distillation. The development of solar distillation has demonstrated its suitability for saline water desalination when the weather conditions are favourable and the demand is not large, i.e., less than

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200 m³/day [1]. Fortunately, solar energy is available in Arab region with relatively high intensity during most of the year. Accordingly, it seemed necessary to study the solar stills that are easy to construct and that could provide us with the necessary daily amount of drinking water, not forgetting the drought that has been prevailing in several areas of Africa for the last two decades. Numerous attempts have been made by many investigators in order to produce fresh water by means of solar energy. The simple solar still of the basin type is the oldest method and improvements in its design have been made to increase its efficiency [2].

A lot of improvements in the simple solar stiller were conducted by scientists to increase its productivity. Some of these modifications, a cascade solar still is properly designed; the operating efficiency can be as high as 60 to 75% [3]. A reduction in the depth of brine in the basin of the roof type still improves the productivity of the still. A wick-type collector-evaporator still showed a production rate of 3.8 to 4.4 Lit/m²/day with an operational efficiency of about 40 to 46% [4]. A stepped basin is also studied [5]. Double-basin still results showed that when the single-basin still produced 2.041 kg/m², the double-basin type produced 3.16 kg/m², i.e. an improvement of about 56% [6]. A passive condenser in the shaded region of a single-slopped still the still efficiency increased by 45% [7]. The performance of a solar still coupled with an external heating system can be improved by replacing the collector with a concentrator. In the concentrator the heat loss is reduced compared to the collector due to the smaller concentrator surface area [8]. Charcoal granules can be used as absorber medium successfully instead of wick-type, black butyl rubber, or asphaltic absorbers. A 15% improvement in productivity over wick-type stills has been attained [9].

The solar collector, which is generally mounted on the roof, absorbs the sun's light energy and converts it into heat energy. Solar collectors heat a fluid that is then used to provide directly or indirectly the household's hot water. They are usually installed on the roof. There are basically three types of thermal solar collectors: flat plate, solar-tube and concentrating.

Concentrating collectors for residential applications are usually parabolic troughs that use mirrored surfaces to concentrate the sun's energy on an absorber tube (called a receiver). This tube contains the heat-transfer fluid, i.e. water.

Line focusing type produces a high density of radiation on a line at the focus. These types of cylindrical parabolic concentrators produce concentration ratios of up to ten. A parabolic trough concentrates the incoming solar radiation onto line along the length of the trough. A tube (receiver) carrying heat transfer fluid is placed along this line, absorbing concentrated solar radiation and heating the fluid inside. The trough must be tracked about one axis. Because the surface area of the receiver tube is small compared to the trough capture area (aperture), temperatures up to 400°C can be reached without major heat loss as a heating system [10].

Elsafty et al. [11] developed a general mathematical model for a solar still that uses parabolic reflector-tube absorber desalination technology. The mode is used to study the still production in different cases. The study revealed that increasing the solar intensity, ambient temperature, efficiency of reflector material, reflector aperture area, and evaporation area increases the unit productivity. On the other hand, increasing wind velocity, saline water depth, condenser emissivity, and condenser thickness have a small effect on the productivity.

2. Experimental test rig

Solar Desalination System (SDS) is proposed as a new trend for water distillation by using the parabolic trough collector. As shown in figure (1) the (SDS) is a semi conventional solar stiller and may be suitable for our needs of fresh water in arid areas. The apparatus components are:

<ul style="list-style-type: none"> • Saline Water Tanks. <ul style="list-style-type: none"> • Salt Water Tank. • Level Control Box (LCB). • Stand of Tanks. 	<ul style="list-style-type: none"> • Solar Desalination Unit. <ul style="list-style-type: none"> • Parabolic Reflector. • Evaporator "Tube absorber". • Condenser & Glass cover. • Stand of Distillation unit.
<ul style="list-style-type: none"> • Fresh Water Jars. 	<ul style="list-style-type: none"> • Manual Tracking System.

A friendly computer model was developed to simulate the solar desalination system (SDS), in order to investigate the effect of various parameters on the performance of the apparatus.

Consequently, this can help conducting a parametric study of the factors likely to affect the thermal performance and the total production of the apparatus, as a first step for the SDS Design [11].

2.1. General description

The developed solar still operation begins with filling the salt water tank. Water is flowing down to the level control box (LCB) and then to the absorber till it reaches the desired level of water in the absorber. The glass cover permits solar radiation to get into the still which is reflected totally to the absorber. The absorber is then heated by direct sun rays and by reflected rays. Consequently, the absorber gets heated up and so the water. Hence, the moisture content of the air trapped between the parabolic trough and the glass cover increases.

The glass cover traps the solar energy inside the still; it also reduces the convective heat losses. The glass cover is sloped to enable the water vapor which condenses on the interior surface to trickle down into collecting channels.

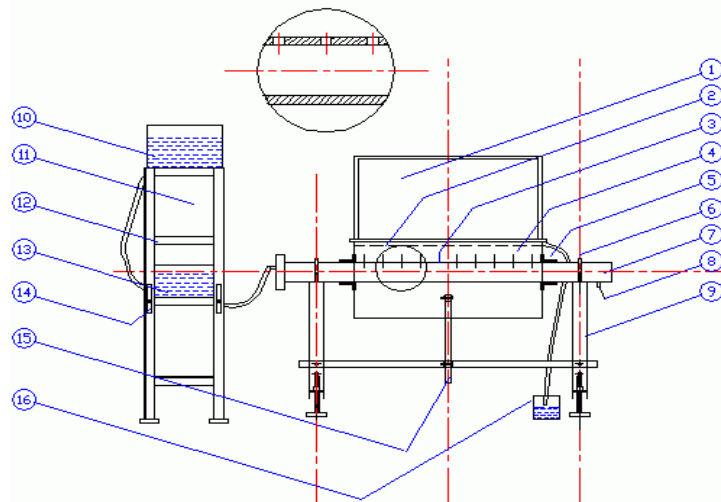


Fig.1. Schematic diagram and parts of solar desalination system

Table 1. Parts of solar desalination system

Item	Description	Item	Description
1	Condenser & Glass cover	9	Stand of distillation unit
2	Water collecting channels	10	Salt Water Tank
3	Holes	11	Flexible Hoses
4	Parabolic Reflector	12	Stand of Tanks
5	Bearing	13	Level Control Box
6	U-bolt	14	Slot
7	Evaporator	15	Electric Motor
8	Drain	16	Fresh Water Jar

2.2. Test Procedures

Throughout the experimental investigations, it was necessary to study the different parameters affecting the thermal performance of the solar stiller. Literature survey showed the important parameters needed to evaluate the still performance are evaporation area, water depth, apparatus direction and solar tracking system utilization. The experimental cases are represented with different modifications on the receiver tube.

After that the second test rig was designed to investigate the effect of changing the dimension of parabolic reflector and the receiver as shown in fig. 2(b).

The third modification was classified by adding simple analog electronic circuit to control the reflector to be facing the sun at any time from sun- rise to sun-set instead of using manual tracking system as shown in fig. 3 (a) and (b).

Fig. 4 shows the automatic sun tracking system from sun rise to sun set. The modification is added to keep the condenser always in shaded region to increase the condensation on it. The last modification was conducted by adding ejector vacuum cycle to the main apparatus as shown in fig. 5.

The basic principle of the cycle is to concentrate solar rays on the main pipe containing saline water in the presence of negative pressure water vapor is then produced. The vacuum is created by the ejector cycle where the vapor is then condensed. Keeping in mind that the project is dependent on solar energy, all electrically operated equipment were required to operate using solar energy, as shown in fig. 6.



Fig.2. (a) First test rig of solar desalination system; (b) Second test rig of solar desalination system



Fig. 3. (a) Light Dependant Resistor (LDR); (b) Tracking Control System

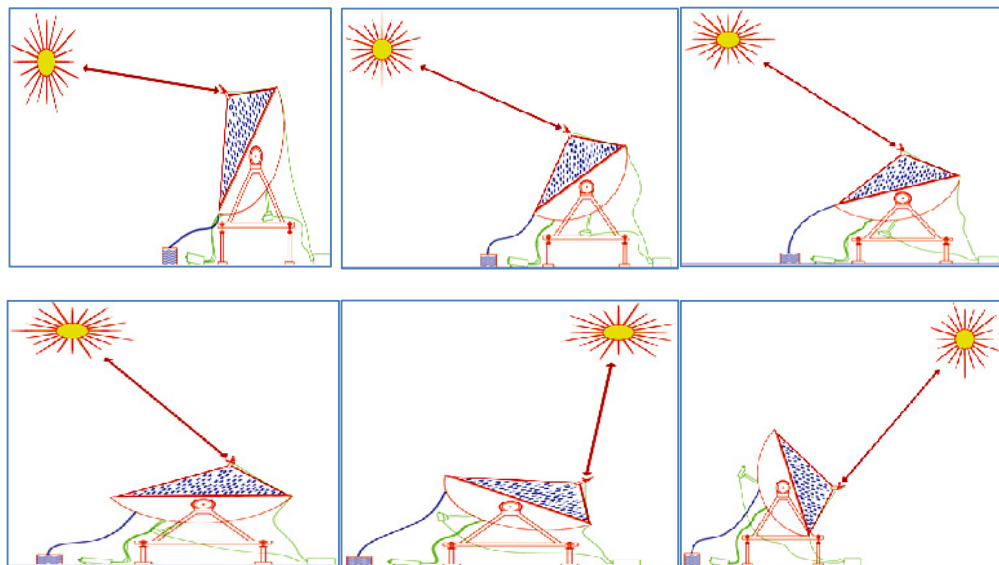


Fig. 4. Different positions of parabolic reflector



Fig. 5. Fourth test rig of solar desalination system

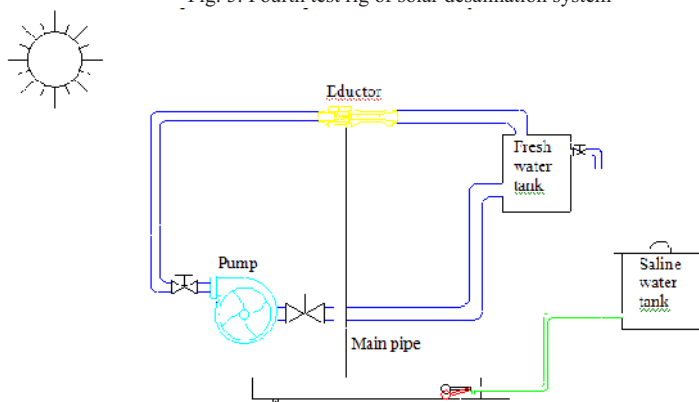


Fig.6. Basic idea of the solar desalination unit with vacuum cycle

The system consists of a water heating unit connected to a vacuum creation unit. A concentrating solar still is used to heat saline water inside a metal pipe. After water evaporates vacuum is created using an ejector cycle in order to remove that vapor. The water vapor is then cooled in a water cycle.

2.3. Results and discussions

The presentation of the enormous amount of results from these experiments is beyond the scope of this publication. The experimental results for SDS are generally presented by plotting the temperatures of different components versus time. The results of first test rig are shown in fig. 7 to 14. Moreover, the effect of using the tracking system on the absorber and water temperature are presented in Fig. 15 and 16 respectively.

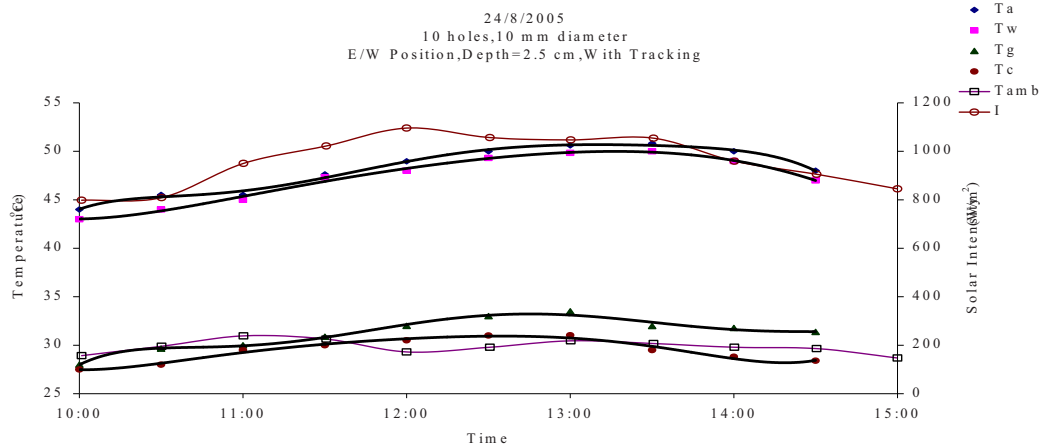


Fig. 7. Experimental data of hourly temperature variation of absorber(T_a), water(T_w), glass cover(T_g) and condenser(T_c), 10 holes, 10mm diameter, E/W Position, Depth=2.5 cm, with tracking.

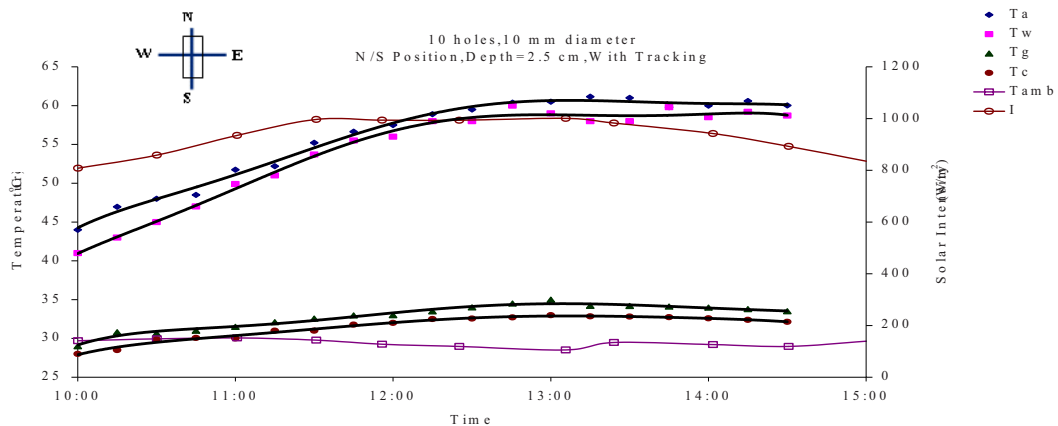


Fig. 8. Experimental data of hourly temperature variation of absorber(T_a), water(T_w), glass cover(T_g) and condenser(T_c), 10 holes, 10mm diameter, N/S Position, Depth=2.5 cm, with tracking.

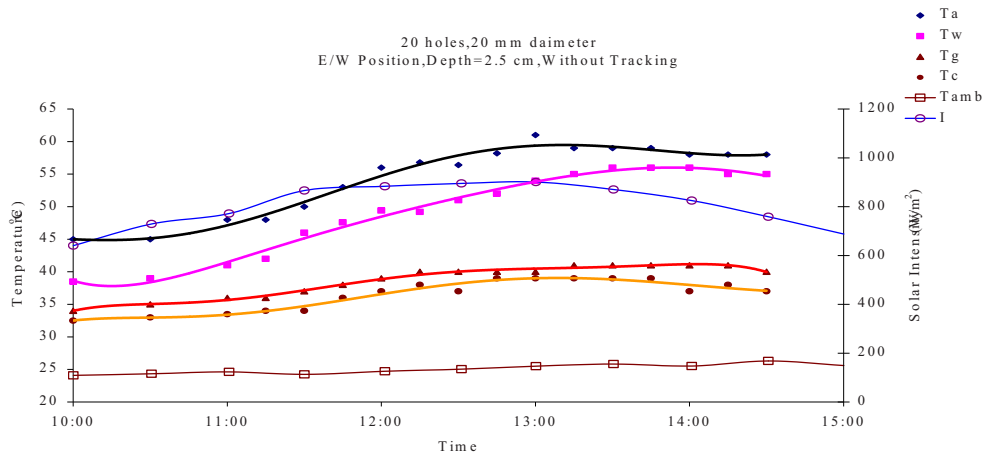


Fig. 9. Experimental data of hourly temperature variation of absorber(Ta), water(Tw), glass cover(Tg) and condenser(Tc), 20 holes, 20mm diameter, E/W Position, Depth=2.5 cm, with tracking.

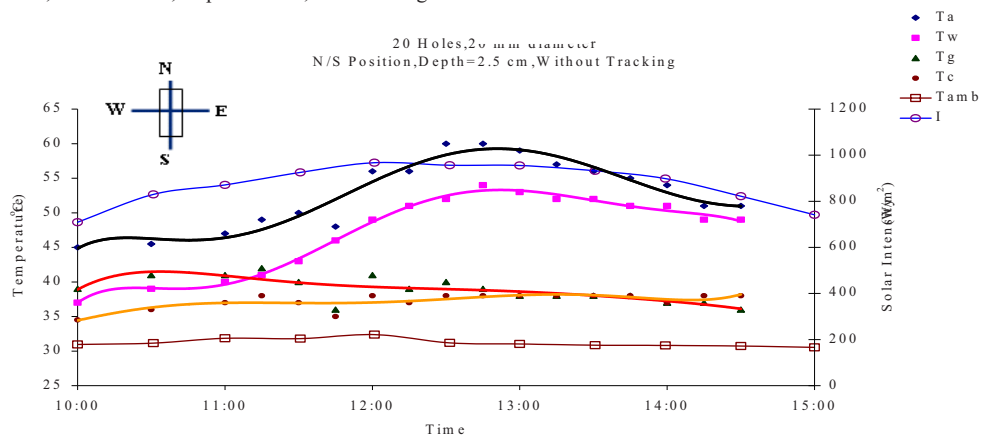


Fig. 10. Experimental data of hourly temperature variation of absorber(Ta), water(Tw), glass cover(Tg) and condenser(Tc), 20 holes, 20mm diameter, N/S Position, Depth=2.5 cm, with tracking.

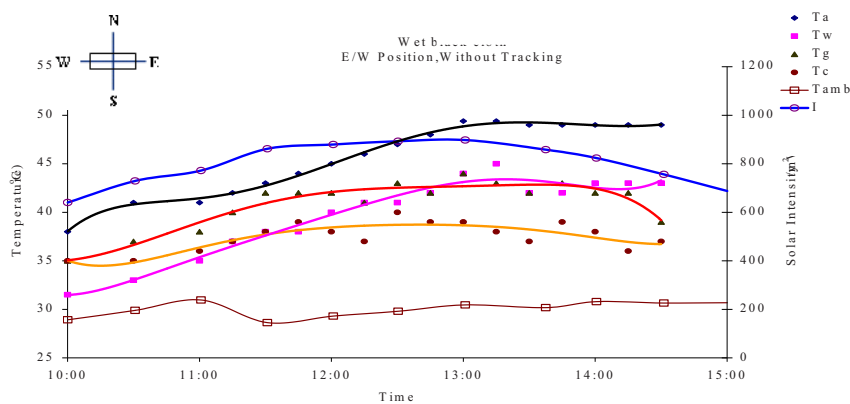


Fig. 11. Experimental data of hourly temperature variation of absorber(Ta), water(Tw), glass cover(Tg) and condenser(Tc), Wet Black Cloth, E/W position without tracking.

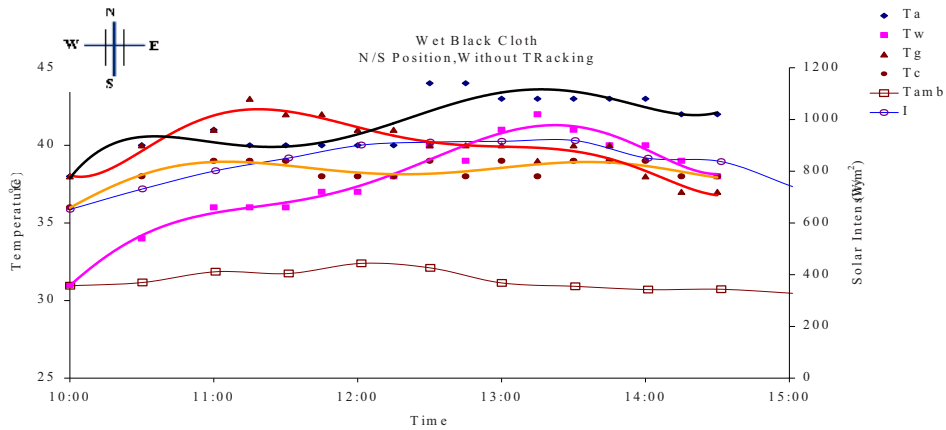


Fig. 12. Experimental data of hourly temperature variation of absorber(T_a), water(T_w), glass cover(T_g) and condenser(T_c), Wet Black Cloth, N/S position without tracking.

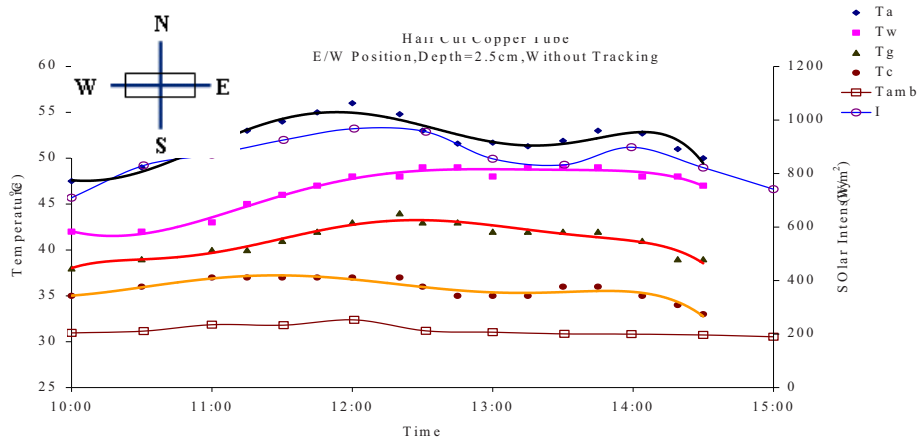


Fig. 13. Experimental data of hourly temperature variation of absorber(T_a), water(T_w), glass cover(T_g) and condenser(T_c), half cut copper tube, E/W position without tracking.

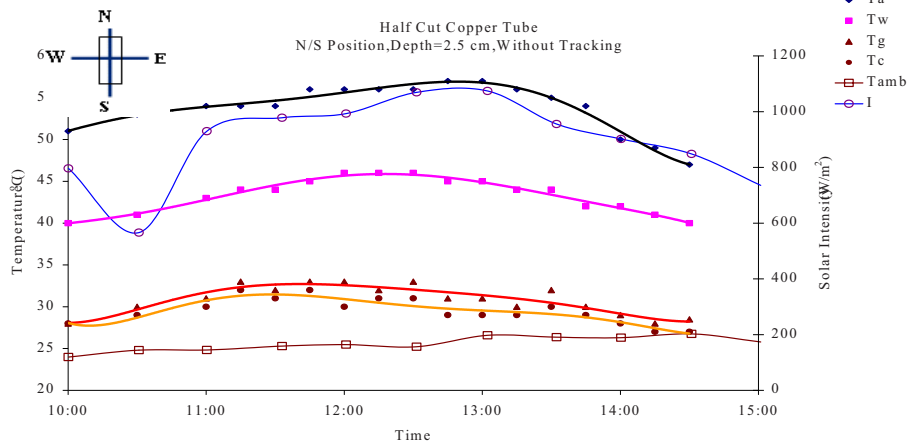


Fig. 14. Experimental data of hourly temperature variation of absorber(T_a), water(T_w), glass cover(T_g) and condenser(T_c), half cut copper tube, N/S position without tracking.

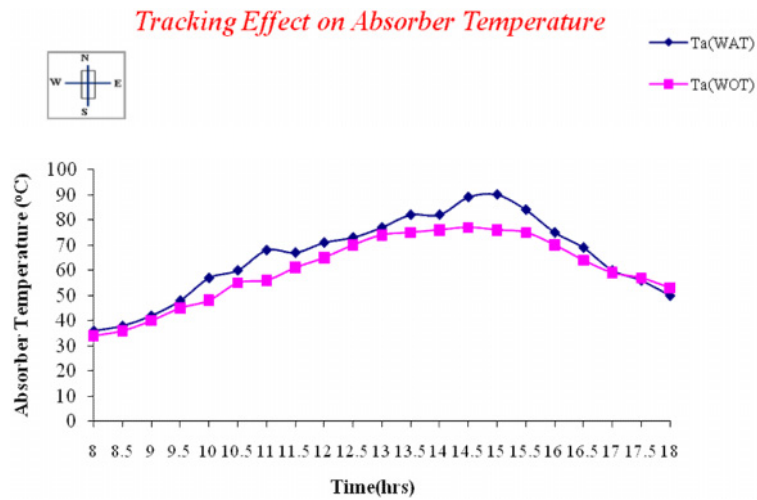
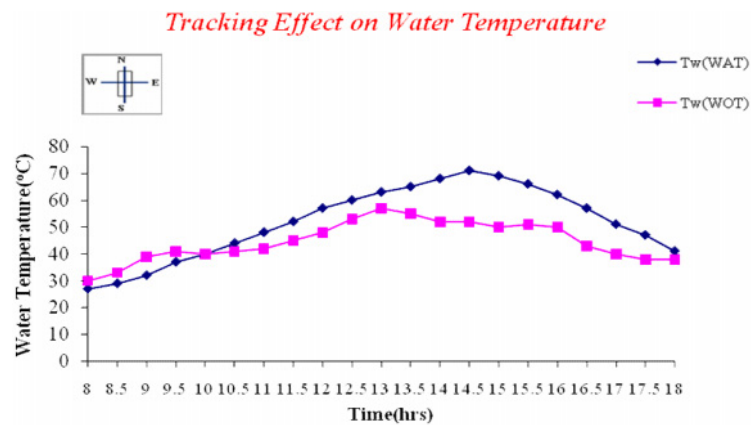


Fig. 15. Tracking effect on absorber temperature



.Fig. 16. Tracking effect on water temperature.

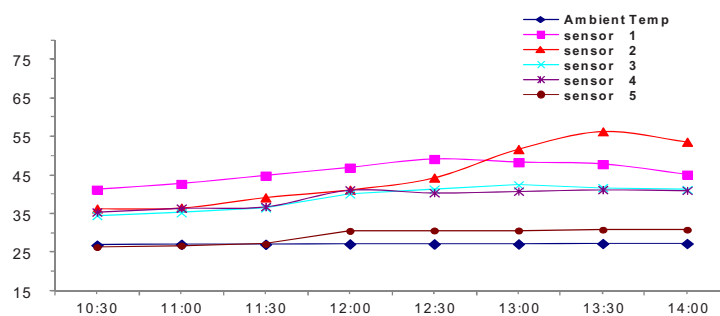


Fig. 17. Experimental data of hourly temperature variation of absorber, water, glass cover and condenser for fourth test rig.

Sensor 1: on the painted part of the pipe -Sensor 2: inside the main pipe to measure salt water temperature-Sensor 3: on the inside of the solar concentrator-Sensor 4: on the side walls of the solar concentrator-Sensor 5: inside the fresh water tank

The following graph shows the relation between the temperatures of the sensors and the time. Fig. 17 show the temperature variation with time of water, receiver, condenser, and glass cover in different cases and modifications. The results represent the primarily case of experimental test, where the apparatus was adjusted in East-West and North-South direction without tracking and using thin layer of water equal 1.5 and 2.5 cm. Comparing figures, the curves show that the thermal performance of the SDS in the E/W direction is better than the N/S Direction. As shown in figures the water temperature is sufficient for water evaporation. Although that, there are no productivity of distilled water was recorded.

Third modification shows the effect of using tracking system on receiver and water temperatures and so on water productivity. Fig.18 indicates the potable water productivity in different cases and modifications. It is clear that the maximum productivity is in the forth modification.

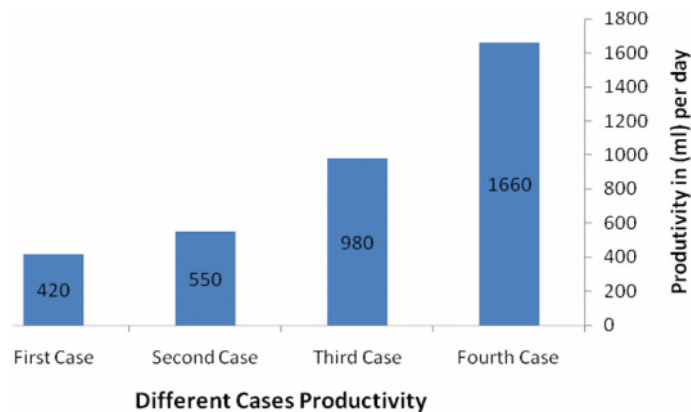


Fig.18. Different cases productivity per day in ml

3. Conclusions

A Solar Desalination System [SDS] is designed and manufactured to produce potable water. A chain of modifications was conducted to increase productivity. This apparatus can be used in remote areas where the solar energy and the source of saline water are abundant. Modifications have great effect on productivity however it coupled with increase in price and more complicated system.

The investigated operational, design and environmental parameters on Solar Desalination System [SDS] performance throughout these tests and modifications revealed that:

- Evaporation surface area has a significant effect on water productivity.
- The thermal performance of Tube Type Solar Still in East-West direction is better than the North-South direction.
- Due to solar tracking system utilization, the condenser was being in the shaded area and led to improving the thermal performance of stiller.
- Adding ejector vacuum cycle to the main apparatus increase the productivity of apparatus but also coupled with increase in initial cost and product of apparatus.

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